The Pennsylvania State University

The Graduate School

College of Engineering

A BIDDING DECISION MODEL FOR SMEs

A Thesis in

Industrial Engineering

by

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

December 2016

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ABSTRACT

A bidding decision model describing the bidding patterns of competitors by *triangular distribution* is developed for small and medium enterprises (SMEs). The model does not rely on past bidding data of competitors; instead, a decision maker's understanding of the competitors is represented by *production costs* and *desire rates* of competitors, which are then used as parameters of triangular distribution. The model integrates production management and cash flow management over multiple periods. It is nonlinear and not smooth, so a heuristic solving process is developed with the Excel evolutionary solver. A numerical example with 36 projects for bid over six months is built to test the effectiveness of the solving process. Over the course of 68 runs, the expected profit is increased to $41,857 when considering all constraints; while $82,500 is the optimal expected profit when considering no constraints at all.

Keywords

Competitive Bidding, Small and Medium Enterprise (SME), Delay in Payment, Triangular Distribution

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

First, I am very grateful to my advisor Dr. Vittaldas V. Prabhu, who guided me through the thesis research and encouraged me to work with confidence. I am very grateful to my reader Dr. Ravindran, who reviewed the thesis. I am very grateful to the coordinator of the IE graduate program Dr. Voigt, who reviewed the thesis. Second, I am very grateful to my friend Pei-Long Ting, whose story of family business inspired me for writing the thesis. I am very grateful to my friend Kai-Wen Tien, who helped me deeply understand ideas and assumptions in my work. I am very grateful to my friend Rakshith Badarinath, who helped me with English writing. Finally, I am very grateful to my parents, who supported me to pursue my master degree in the United States.

Chapter 1

Introduction

Bidding is a process that determines who can be the owner of a specific property or who can provide a specific service. International oil companies bid for oil fields from governments. Construction companies bid for building projects from customers. The pricing of daily goods in retail stores can also be regarded as a method of bidding. Companies always want to develop an optimal bidding strategy, which can help them survive and make optimal profits. Characteristics of a bidding model depend on the business environments and the properties of companies. A successful model for one company may not be suitable for another company. The bidding model in this thesis is developed specifically for small and medium enterprises (SMEs) and is inspired by a small Taiwanese manufacturer that produces coal pipelines for power stations.

Generally, SMEs have few resources to build a sophisticated strategy; thus, the model in this thesis presents and processes key decision factors in a concise way. The model considers the bidding patterns of competitors but does not rely on historical bidding data to build the bidding patterns. Instead, it describes the bidding patterns by *triangular distribution* with parameters that are determined by the ceiling bidding prices of projects, production costs of competitors, and *desire rates* of competitors. Desire rates implicitly contain management information about competitors. Furthermore, SMEs are generally vulnerable to cash flow insufficiency; therefore, the model integrates cash flow management with production management to ensure that companies always have sufficient cash for short-term or long-term liability. Finally, the entire model is developed and solved in Excel, which is accessible to most SMEs.

Chapter 2

Literature Review

2.1 Competitive Bidding

The first paper on competitive bidding (Friedman 1956) lists several facts about competitive bidding. First, a competitive bidding problem can be either open or closed. Open bidding is also known as an *auction*. A biding problem is open when competitors openly bid until the final price is achieved, that is, no competitors submit higher prices than the last bidder. A bidding problem is closed when each competitor submits his/her own price without knowing the other bidders' prices and the best price is chosen and announced openly. Competitive bidding occurs formally or informally in business. The pricing of products in retail stores can also be regarded as a method of competitive bidding.

Second, competitive bidding problems can be modeled by game theory or analytic methods. Game theory methods are useful for the cases in which the number of the competitors is few and certain, while analytic methods are more useful for the cases in which the number of competitors is large or uncertain. Different cases have different properties and should be treated differently. A model that is useful in some situations may not be useful in other situations.

Third, successful competitive bidding models exist in industry, but the details of those models are not revealed or published because they are deemed to be trade secrets. The model presented by Friedman (1956) was paraphrased from a successful industry case per the author.

Fourth, the objectives of competitive bidding problems can be 1) maximizing the expected profit, 2) minimizing the expected loss, 3) minimizing the profits of competitors to make those competitors weaker in the long run, or 4) maximizing the probability of winning a project. Other objectives can also be found in competitive bidding problems. Which objective should be used depends on the situation, but the most common objective is maximizing the expected profit.

Generally, to solve any bidding problem, one must know the uncertainties in the problem and describe the uncertainties probabilistically. The two major uncertainties in bidding are the uncertainty of winning a project and the uncertainty of the production cost for producing the project. No one can be sure that they will win a specific project. No business can be sure that the estimated cost of a project before production is exactly equal to the final cost, especially when the project is large, customized, and unique (e.g., transportation systems, nuclear plants, or aircrafts).

Friedman (1956) estimated the probability of winning a project in a closed bidding problem as follows. First, a decision maker should collect information concerning the previous bidding prices submitted by competitors. Second, the decision maker can build distributions of those previous bidding prices submitted by the competitors. Finally, the probability of winning can be determined based on the distributions. Friedman (1956) generalized the previous process to cases where the number of competitors is uncertain. In these cases, the number of competitors is modeled as a random variable, and each competitor is modeled as an *average bidder*, whose behavior is based on previous information about competitors. Friedman (1956) estimated the production cost of a project by building a distribution from previous cost estimates and actual costs. Although Friedman (1956) did not present data to verify the model, key issues in bidding problems were pointed out, and those issues are still being studied by researchers.

Gates (1967) presented seven bidding strategies based on Gates' industry experience. Each strategy is developed for different situations. First, a lone-bidder strategy assumes that the probability of winning a specific project depends only on how the customer of the project feels satisfied about the bidding price submitted by the only bidder. If the customer thinks the bidding price is too high to accept, he/she can reject the only bidder and wait for new bidders or a lower bidding price from the original bidder.

Second, a two-bidder strategy assumes that each bidder has only two bidding prices to submit, either the original one or the increased one, so the case resembles a game theory problem. Third, a many-bidders strategy shows how a company can estimate the probability of winning a specific project based on the previous bidding prices submitted by the company and on the number of competitors. Fourth, an all-bidders-known strategy estimates the probability of winning a project from the probabilities of winning against each competitor. The difference between the third and fourth strategy lies in whether the company has enough information about competitors to build the bidding pattern of each competitor to estimate the probability of winning against each competitor individually. If the company does not have information about the competitors, it can only use its own previous bidding prices (not necessarily successful) to estimate the probability of winning, which is the third strategy.

Fifth, a number-of-bidders-known strategy estimates the probability of winning a project from the probabilities of winning against each *typical* competitor individually. It assumes that a company not only knows the exact number of the competitors but also knows information about individual competitors. Sixth, a least-spread strategy not only considers the probability of winning a project but also tries to minimize the difference between the best price and the second-best price. Seventh, the unbalanced bidding strategy considers unit price proposals.

Friedman (1956) studied competitive bidding problems from a theoretical perspective; Gates (1967) studied competitive bidding problems from an industrial perspective and did not try to build a theoretical framework for all kinds of competitive bidding problems. However, Friedman (1956) and Gates (1967) together laid the foundations for later research on competitive bidding. The later research still focuses on how to estimate the probability of winning a project and the production cost of a project.

McAfee and McMillan (1987) discussed auctions and bidding from the perspective of economics. Rothkopf and Harstad (1994) reviewed the research of competitive bidding from the perspectives of operations research and economics. Runeson and Skitmore (1999) reviewed bidding research from the perspectives of price theory, game theory, decision theory, and auction theory. Runeson and Skitmore (1999) investigated the criteria for evaluating a bidding model, including the ability to produce accurate forecasts as well as applicability. They also discussed alternative objective functions in addition to maximizing profit and the accuracy of cost estimation that will affect a submitted bidding price.

2.2 Small and Medium Enterprises (SMEs)

In 2016, the U.S. Small Business Administration defined *small business* as a business entity that employs less than 500 employees for manufacturing and mining industries and generates less than $7.5 million for nonmanufacturing industries. Scott and Bruce (1987) stated that a small business is generally held by a small group, directly managed by the owners, and operates locally.

Welsh and White (1981) argued that small businesses are different from big businesses not only because of the business scale but also because of a special condition called *resource poverty*. Small businesses generally cannot afford professional accounting services like big businesses can. Resource poverty makes small businesses more vulnerable than big businesses to price cutting and external forces (e.g., changes in government regulations or interest rates). Additionally, small businesses can fail more easily than big businesses if they make misjudgments. Welsh and White (1981) provided examples to show how a growing small business can fail because an owner assumes that management concepts used for big businesses can be directly applied to his/her small business without adaptation. With the failure example, Welsh and White (1981) argued that small businesses need different management concepts and tools than those of big businesses.

Mach and Wolken (2006) stated that 60% of the small businesses in the 2003 federal survey used trade credit for 30 or 60 days. Use of trade credit was mostly seen among construction, manufacturing, and wholesale and retail firms because their non-labor costs were larger than their labor costs. Additionally, trade credit is a method of financing provided by suppliers and is important for small businesses because it is more difficult for small businesses to get loans from financial institutions. Moreover, 59% of the small businesses that used trade credit in the 2003 federal survey paid the bills by the due dates; the firms that did not pay by the due dates delayed their payments by 30% of the trade credits.

Chapter 3

Bidding Decision Model

The thesis research is inspired by a small Taiwanese manufacturer that produces coal pipelines for power stations and follows the following bidding decision process:

1. When power stations must install new pipelines or maintain old pipelines, they will announce their needs publicly or invite the small manufacturer to bid for the projects (pipeline installation or maintenance) with other competitors who are also invited.
2. The small manufacturer will review its own working capital level, accounts payable, and accounts receivable to determine whether it is capable of investing in the new projects. The small manufacturer will also check its production capacity, storage space, and labor to determine whether it can produce the projects.
3. The small manufacturer will analyze the competitors' capabilities to invest in and produce the projects and their desires to win the projects.
4. The small manufacturer will determine a bidding decision, including which projects to bid on and how much to bid.

The above process reveals several important decision factors that are shared by many companies. First, a company can decide whether to join a specific bidding game. Second, a bidding price affects the probability of winning a project as well as the profit from providing the project. Third, the company should understand whether it is capable of investing in and producing the project once it wins the project. Fourth, the company also needs to analyze the competitiveness of the competitors.

3.1 Description of the Model

The core of the model is to estimate the probabilities of winning projects (bids) by studying the bidding patterns of competitors. The model uses triangular distribution to describe the uncertainty of winning a project. The parameters of distributions are determined only by competitors' production costs of projects and the *desire rates* of winning projects and ceiling bidding prices of projects set up by customers. The purposed simplicity of estimating the probabilities is to reflect that SMEs generally have few resources to analyze information about competitors and customers thoroughly.

The model has production constraints (i.e., production capacity, storage space, labor, and cash flow constraints, such as accounts receivable and accounts payable). It is assumed that raw material can be shipped immediately from suppliers once an order is made, so there is no need to store raw material; hence, there is no constraint of raw material. This assumption is valid for many SMEs that have collaborated with their suppliers for a long time, and their suppliers find it is beneficial to do so. Furthermore, the model assumes that the production time of a project can be one, two, or three months. It also considers delays of payments to suppliers and from customers and assumes that the time of delay can be one, two, or three months.

Parameters

T Number of months considered when making bidding decisions.

n_i Number of projects available for bid in the i^{th} month.

n_{ij} Number of competitors bidding for project (i, j).

c_{ijk} k^{th} competitor's production cost for project (i, j).

d_{ijk} k^{th} competitor's desire rate for project (i, j); $0 \leq d_{ijk} \leq 1$.

$ceil_{ij}$	Ceiling bidding price of project (i, j), set up by customer.
t_{ij}	Production time of project (i, j), set by customer.
tc_{ij}	Permissible delay time of payment from customer of project (i, j).
ts_{ij}	Permissible delay time of payments to suppliers of project (i, j).
u_{ij}	Overall production capacity needed for project (i, j).
s_{ij}	Overall storage space needed for project (i, j).
l_{ij}	Overall labor needed for project (i, j).
c_{ij}	Overall production cost of project (i, j), (i.e., the money that will be paid to the suppliers of project (i, j)).
u_i	Production capacity available in the i^{th} month.
s_i	Storage space available in the i^{th} month.
l_i	Labor available in the i^{th} month.
ubc_i	Upper bound of payments to suppliers in the i^{th} month.
lbc_i	Lower bound of payments from customers in the i^{th} month.
ss_i	Lower bound of sales in the i^{th} month.
roi	Lower bound of ROI.

The length of time considered in the model is T months. In the i^{th} month, there are n_i projects available for bid. The j^{th} project in the i^{th} month is denoted as project (i, j). The order among projects in each month is simply for numbering and has no other implications.

For project (i, j), there are n_{ij} competitors. A decision maker will estimate the k^{th} competitor's production cost of project (i, j), denoted as c_{ijk}. The competitors will not reveal their own production costs, but the decision maker can still estimate the costs from his/her experience with those competitors. Additionally, the decision maker will estimate the k^{th} competitor's desire rate of project (i, j), denoted as d_{ijk}, and can determine how a competitor wants a project based on the recent operational and financial performance of that competitor. If the competitor has recently performed poorly, it will eagerly want a project to improve performance and will have a high desire rate for the project. The customer of project (i, j) will set up a ceiling bidding price, denoted as $ceil_{ij}$, than which any reasonable bidding price submitted by competitors should not be higher. Moreover, c_{ijk}, d_{ijk}, and $ceil_{ij}$ are used to estimate the probability of winning project (i, j).

The customer of project (i, j) will set up not only a ceiling bidding price but also a production time of project (i, j), denoted as t_{ij}. A production time of more than one month means that the customer can wait for the project being produced over several months, and the parts of the project can be shipped monthly. Additionally, the customer can pay for project (i, j) monthly. By so doing, both the customer and the company can lessen their cash burdens and have additional average storage spaces. The permissible delay of payment from the customer of project (i, j) is denoted as tc_{ij}. The permissible delay of payment to the suppliers of project (i, j) is denoted as ts_{ij}. The permissible delay can be one, two, or three months, as is often seen in the industry.

The overall production resources needed for project (i, j) are production capacity, storage space, and labor, which are denoted as u_{ij}, s_{ij}, and l_{ij}, respectively, and are represented as the percentage of full capacity. The overall production cost for project (i, j) is denoted as c_{ij}. The production capacity, storage space, and labor that are available for producing projects in each month are limited, denoted as u_i, s_i, and l_i, respectively, and are represented as the percentage of full capacity. To stabilize cash flow, a decision maker sets up an upper bound of payments to suppliers in each month, denoted as ubs_i, and a lower bound of payments from customers in each month, denoted as lbc_i. The decision maker also wants to maximize profit while maintaining sales and ROI at certain levels, denoted as ss_i and roi, respectively.

Variables

x_{ij} To bid or not to bid for the project (*i*, *j*) (binary variable).

p_{ij} Price to bid for the project (*i*, *j*).

A pair of decision variables (x_{ij}, p_{ij}) corresponds to a specific project. Since there are $\sum_{i=1}^{T} n_i$ projects available for bid, there are $2\sum_{i=1}^{T} n_i$ decision variables in the model.

Objective

The objective of the bidding decision model is to maximize the expected profit, which can be written as follows:

$$max \sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij}(p_{ij} - c_{ij})w_{ij}(p_{ij})$$

where $w_{ij}(p_{ij})$ is the probability of winning project (*i*, *j*) given a bidding price p_{ij}.

Probability of Winning Bid

The core of the bidding decision model is to estimate the probability of winning a project. The probability of winning project (*i*, *j*), given bidding price p_{ij}, is denoted as $w_{ij}(p_{ij})$. The structure details of the function $w_{ij}(p_{ij})$ are described below:

$$w_{ij}(p_{ij})$$

$$= w_{ij}\left(p_{ij} \parallel c_{ij1} \ldots c_{ijn_{ij}}; d_{ij1} \ldots d_{ijn_{ij}}; ceil_{ij}\right)$$

$$= \prod_{k=1}^{n_{ij}} 1 - F\left(p_{ij} \parallel c_{ijk}; d_{ijk}; ceil_{ij}\right),$$

where $F\left(p_{ij} \parallel c_{ijk}; d_{ijk}; ceil_{ij}\right)$ is the probability that p_{ij} is higher than the bidding price submitted by the k^{th} competitor for project (i, j) and where $F\left(x \parallel c_{ijk}; d_{ijk}; ceil_{ij}\right)$ is a triangular cdf with lower limit $=c_{ijk}$, upper limit $=ceil_{ij}$, and mode $=c_{ijk} + (1 - d_{ijk})(ceil_{ij} - c_{ijk})$. Moreover, $f\left(x \parallel c_{ijk}; d_{ijk}; ceil_{ij}\right)$ is the corresponding triangular pdf and so-called bidding pattern of the competitor. A bidding pattern indicates the probability that a competitor will submit a bidding price to win a project.

A bidding pattern of a specific competitor is modeled as a triangular distribution. The lower limit of the specific triangular distribution is just the production cost of the specific competitor for the project (i.e., c_{ijk}). The upper limit of the specific triangular distribution is the ceiling bidding price of the project set up by the customer of the project (i.e., $ceil_{ij}$). The mode of the specific triangular distribution is determined by the specific competitor's desire rate for the project. If the competitor is very determined to win the project, then the mode of the specific triangular distribution will be close to the lower limit, while if the competitor does not want to win the project, the mode of the distribution will be closer to the upper limit. Once the bidding pattern of a specific competitor is known, a decision maker can calculate the probability of winning against the specific competitor, given bidding price, and hence can calculate the overall probability of winning against all competitors for the same project.

Consider a simple example in which an SME must compete for a project with three competitors (Table 3-1). The production cost of the SME for the project is $10,000. The ceiling bidding price of the project is $13,000. Figure 3-1 shows the bidding patterns of the competitors. Figure 3-2 shows the SME's probabilities of winning the project given the bidding prices submitted by the SME.

Table 3-1 Production Costs and Desire Rates of Competitors

	Production Cost	Desire Rate
Competitor A	$9,000	90%
Competitor B	$10,000	60%
Competitor C	$11,000	30%

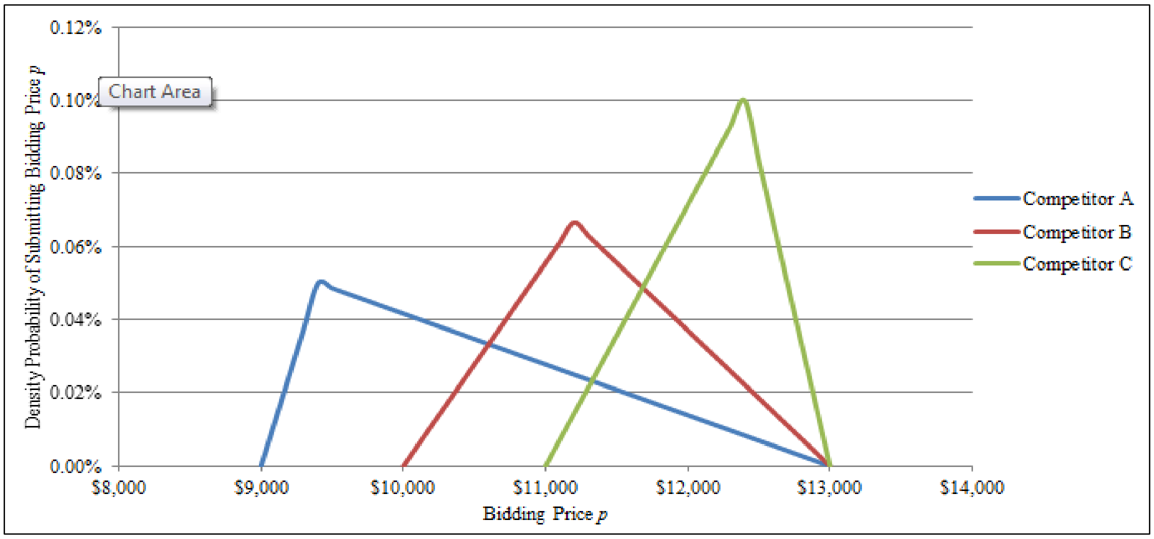


Figure 3-1 Bidding Patterns of Competitors

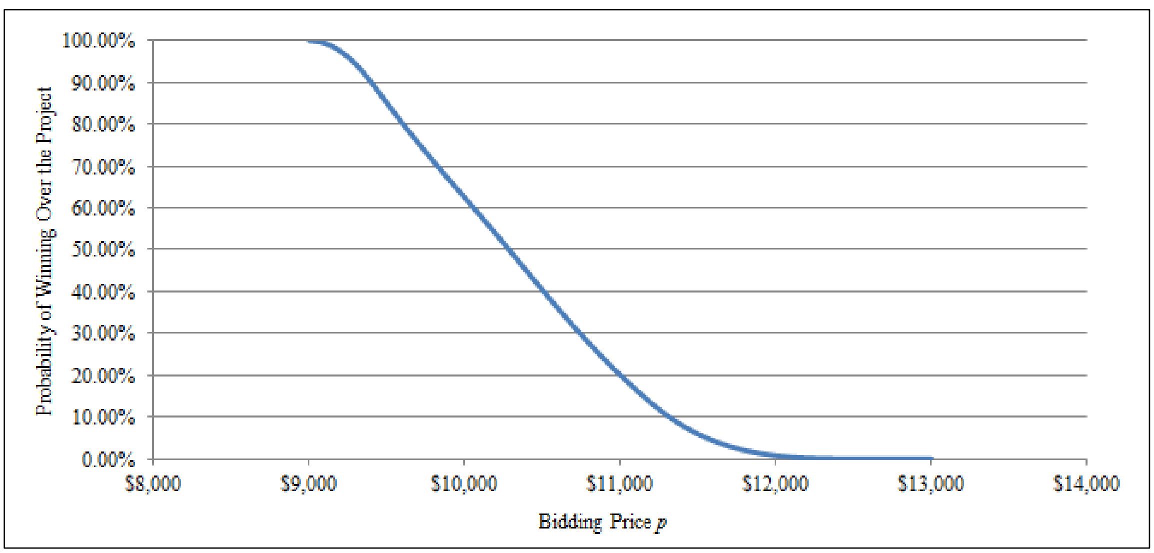


Figure 3-2 Probability of Winning a Project

Figures 3-3 shows the expected sales and costs of the project given the bidding prices *p* submitted by the SME. Figures 3-4 shows the expected profits of the project given the bidding prices *p* submitted by the SME. Figures 3-5 shows the ROI of the project given the bidding prices *p* submitted by the SME. When there is more than one project for bid, the ROI is generally nonlinear function of the bidding prices.

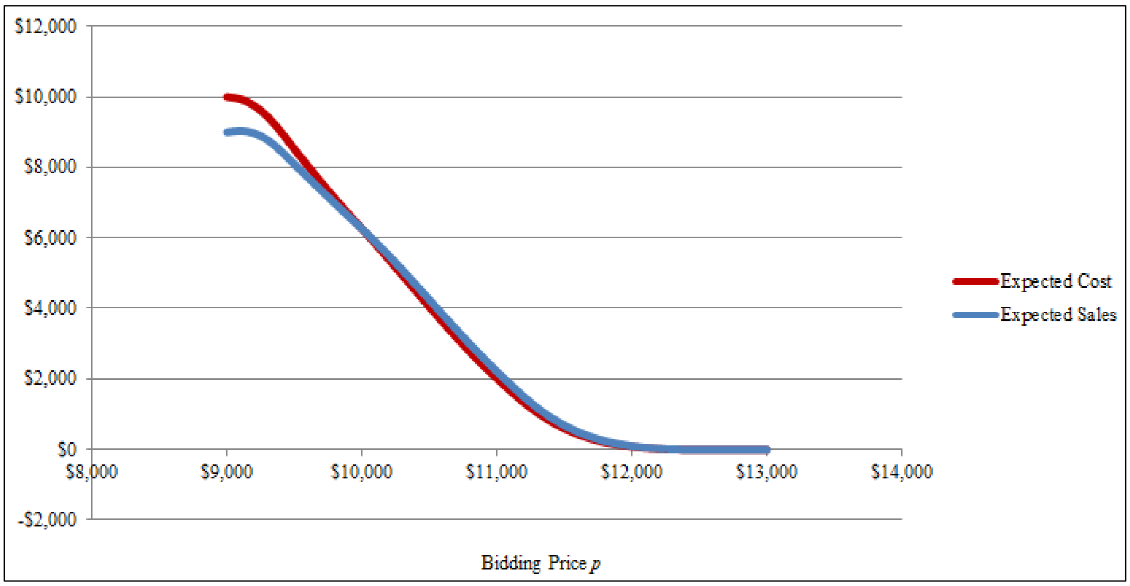


Figure 3-3 Expected Sales and Cost of Project

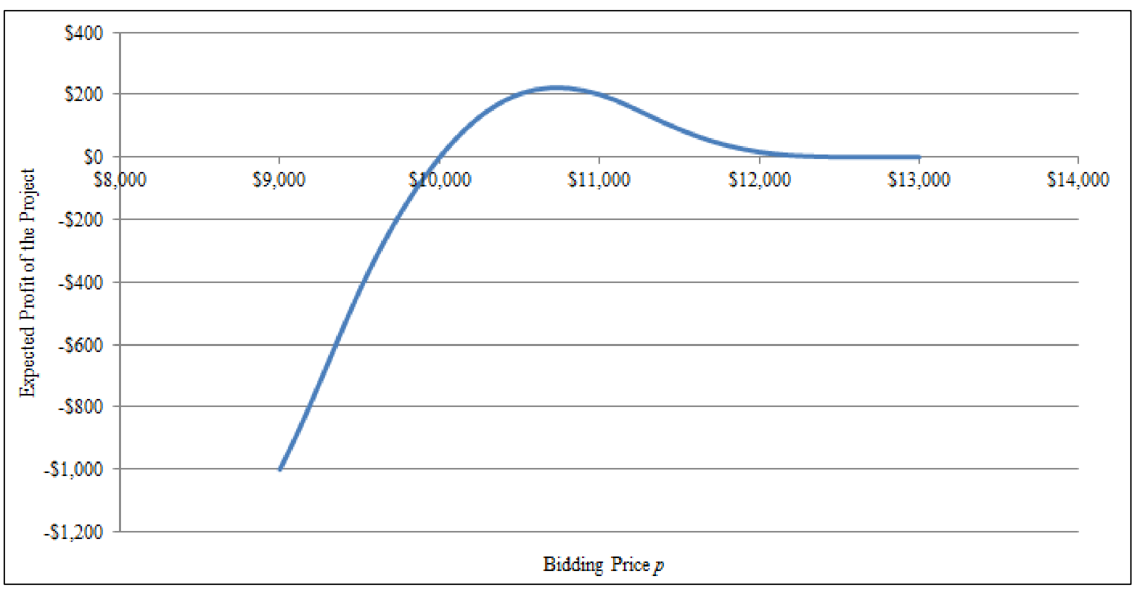


Figure 3-4 Expected Profit of Project

Figure 3-5 ROI of Project

The reason triangular distribution is used to model bidding patterns of competitors is that SMEs generally cannot afford to collect and analyze sophisticated information about competitors. For example, the small Taiwanese manufacturer inspiring this thesis research says that it cannot afford to collect and analyze the operational and financial performances of its competitors quantitatively, but it can still discover information about the competitors from discussions with the suppliers and customers of the competitors. Triangular distribution is also called “lack of knowledge” distribution and is used heavily in situations where a rough modeling of uncertainty must be built even if there is only limited information.

Constraints

The constraints of the *production capacity* are as follows:

$$\sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}\frac{u_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k) \le u_k \qquad k = 1, 2, 3, \ldots T$$

The meaning of each term in the production capacity constraints is as follows:

$x_{ij}u_{ij}$	Overall production capacity needed for project (*i*, *j*).
$x_{ij}\frac{u_{ij}}{t_{ij}}$	Production capacity needed for project (*i*, *j*) in each month when the production of project (*i*, *j*) occurs; (t_{ij} is the number of months that project (*i*, *j*) will be produced. In other words, it takes t_{ij} months to finish project (*i*, *j*).)
$x_{ij}\frac{u_{ij}}{t_{ij}}w_{ij}(p_{ij})$	Expected production capacity needed for project (*i*, *j*) in each month in which the production of project (*i*, *j*) occurs.
$x_{ij}\frac{u_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k)$	Expected production capacity needed for project (*i*, *j*) in the k^{th} month; ($\mathbf{1}_{[i,i+t_{ij}-1]}(k)$ is the indicator function that determines whether project (*i*, *j*) will be being produced in the k^{th} month.)
u_k	Production capacity available in the k^{th} month.

The constraints of the *storage space and labor*, respectively, are as follows:

$$\sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}\frac{s_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k) \le s_k \qquad k = 1, 2, 3, \ldots T$$

$$\sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}\frac{l_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k) \le l_k \qquad k = 1, 2, 3, \ldots T$$

The meaning of each term in the storage space and labor constraints is the same as the meaning of each term in the production capacity constraints just explained.

The constraints of the *payments to suppliers* are as follows:

$$\sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}\frac{c_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k-ts_{ij}) \leq ubs_k \qquad k=1,2,3,\ldots T$$

The meaning of each term in the constraints is as follows:

$x_{ij}c_{ij}$	Overall production cost for project (*i*, *j*) (i.e., the money that will be paid to the suppliers of project (*i*, *j*)).
$x_{ij}\frac{c_{ij}}{t_{ij}}$	Money that should be paid to the suppliers of project (*i*, *j*) in each month when the payments are due; (t_{ij} is the number of months that project (*i*, *j*) will be produced and the number of the months that the payments occur. In other words, it takes t_{ij} months to make all payments.)
$x_{ij}\frac{c_{ij}}{t_{ij}}w_{ij}(p_{ij})$	Expected money should be paid to the suppliers of project (*i*, *j*) in each month when the payments are due.
$x_{ij}\frac{c_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k-ts_{ij})$	Expected money that should be paid to the suppliers of project (*i*, *j*) in the k^{th} month; ($\mathbf{1}_{[i,i+t_{ij}-1]}(k-ts_{ij})$ is the indicator function that determines whether the payments to the suppliers of project (*i*, *j*) will be due in the k^{th} month, and ts_{ij} is the permissible time of payment delay.)
ubs_k	Upper bound of the payments to suppliers in the k^{th}

	month.

The constraints of the *payments from customers* are as follows:

$$lbc_i \leq \sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}\frac{p_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k-tc_{ij}) \qquad k=1,2,3,\ldots T$$

The meaning of each term in the constraints:

$x_{ij}p_{ij}$	Bidding price of project (*i*, *j*) (i.e., the overall money that will be paid from the customer of project (*i*, *j*)).
$x_{ij}\frac{p_{ij}}{t_{ij}}$	Money that should be paid from the customer of project (*i*, *j*) in each month when the payments are due; (t_{ij} is the number of months that project (*i*, *j*) will be produced and the number of the months that the payments occur. In other words, it takes t_{ij} months to make all payments.)
$x_{ij}\frac{p_{ij}}{t_{ij}}w_{ij}(p_{ij})$	Expected money that should be paid from the customer of project (*i*, *j*) in each month when the payments are due.
$x_{ij}\frac{p_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k-tc_{ij})$	Expected money that should be paid from the customer of project (*i*, *j*) in the k^{th} month; ($\mathbf{1}_{[i,i+t_{ij}-1]}(k-tc_{ij})$ is the indicator function that determines whether the payments from the customer of project (*i*, *j*) will be due in the k^{th} month, and tc_{ij} is the permissible time of payment delay.)
lbc_k	Lower bound of the payments from customers in k^{th} month.

The payment constraints are needed because failure to control cash flow will result in bankruptcy. In the short term, cash flow is equally important as profit.

The constraints of *sales* are as follows:

$$ss_i \leq \sum_{j=1}^{n_i} x_{ij} p_{ij} w_{ij}(p_{ij}) \qquad i = 1, 2, 3, \ldots T$$

The sales constraints are needed because the business scale is important for long-term competitiveness.

The constraint of *ROI* is as follows:

$$roi \leq \frac{\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij}(p_{ij} - c_{ij}) w_{ij}(p_{ij})}{\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} c_{ij} w_{ij}(p_{ij})}$$

The ROI constraint is needed because investment efficiency is also a key indicator of management.

Complete Formulation of the Bidding Decision Model

$$max \sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij}(p_{ij} - c_{ij}) w_{ij}(p_{ij})$$

$s.t.$

$$\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} \frac{u_{ij}}{t_{ij}} w_{ij}\left(p_{ij}\right) \mathbf{1}_{[i,i+t_{ij}-1]}(k) \le u_k \qquad k = 1, 2, 3, \dots T$$

$$\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} \frac{s_{ij}}{t_{ij}} w_{ij}\left(p_{ij}\right) \mathbf{1}_{[i,i+t_{ij}-1]}(k) \le s_k \qquad k = 1, 2, 3, \dots T$$

$$\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} \frac{l_{ij}}{t_{ij}} w_{ij}\left(p_{ij}\right) \mathbf{1}_{[i,i+t_{ij}-1]}(k) \le l_k \qquad k = 1, 2, 3, \dots T$$

$$\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} \frac{c_{ij}}{t_{ij}} w_{ij}\left(p_{ij}\right) \mathbf{1}_{[i,i+t_{ij}-1]}(k - ts_{ij}) \le ubs_k \qquad k = 1, 2, 3, \dots T$$

$$lbc_i \le \sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} \frac{p_{ij}}{t_{ij}} w_{ij}\left(p_{ij}\right) \mathbf{1}_{[i,i+t_{ij}-1]}(k - tc_{ij}) \qquad k = 1, 2, 3, \dots T$$

$$ss_i \le \sum_{j=1}^{n_i} x_{ij} p_{ij} w_{ij}(p_{ij}) \qquad i = 1, 2, 3, \dots T$$

$$roi \le \frac{\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij}(p_{ij} - c_{ij}) w_{ij}(p_{ij})}{\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} c_{ij} w_{ij}(p_{ij})}$$

3.2 Characteristics of the Model

1. **The model describes bidding patterns by *triangular distribution* with the parameters that are determined only by ceiling bidding prices of projects, production costs of competitors, and *desire rates* of competitors.** The model attributes the uncertainty of winning a project to the uncertainties of bidding prices submitted by competitors. It further attributes the uncertainty of submitted bidding prices to the uncertainties of production costs of competitors for that project and the uncertainties of how much competitors want to win that project. The uncertainties of production costs of competitors are not treated explicitly by the model in this thesis, and it is the responsibility of a decision maker to estimate the production costs of competitors by his/her experiences, while the uncertainties of how much competitors want to win a project are quantified by *desire rates.* Distributions of submitted bidding prices are modeled as triangular distributions.

2. ***Desire rates* reflect management situations of competitors.** Although the model cannot explicitly consider all management information of the competitors, the management situation of competitors can be reflected by the desire rates of the competitors. A competitor who wins few projects in the first months of the year may have a high desire rate for new projects in the months that follow because the competitor’s production resources are underutilized, while a competitor that has already won several projects in the first months of the year may have a low desire rate for new projects in the months that follow because the competitor’s production resources are mostly utilized. A competitor who wants to drive others out of the market in the long run may also have a high desire rate for new projects no matter whether those projects can bring profits. A competitor who wants to expand business scale with newly added machines and personnel may also have a high desire rate for new projects. Generally,

desire rates depend on management situations, growth strategies, and personalities of competitors' decision makers. To produce accurate desire rates of competitors requires many years of experience with the competitors.

3. **The model includes the uncertainty of winning a project in all the resource constraints.** For most models, the uncertainty of winning a project is only included in objective functions, not in resource constraints. Ignorance of the uncertainty of winning a project in resource constraints usually makes those constraints linear, which makes it easier to solve the models. However, a model that ignores the uncertainty of winning a project in the resource constraints must produce solutions that substantially underutilize production resources. The appearance of uncertainty in the resource constraints of the thesis model makes the model closer to reality but more difficult to solve.

4. **The model integrates production management with cash flow management.** Since cash flow management plays a key role in the survival of a business, especially for SMEs, the thesis model takes in account and quantifies the cash flow generated by projects. Cash flows occur when payments (to suppliers or from customers) occur. Delay in payment is permissible. The model allows the delay in payment to be one, two, or three months. The model allows a decision maker to know not only the profit, sales, and cost of a project but also the cash inflow (payments from customers) and outflow (payments to suppliers) in each month generated by that project. Once the decision maker knows the overall cash flow generated by a specific bidding decision, he/she can choose the bidding decisions that will provide the most preferred cash flow. After the decision maker understands and analyzes his/her company's growth goal, accounts payable, and accounts receivable, he/she can know

what the preferable cash flows should be. Well-managed cash flow guarantees survival of his/her company.

5. **The model considers not only trade-offs between projects in the same months but also trade-offs between projects in different months.** For many models, their timelines are one-unit periods, so those models only consider trade-offs between projects in the unit periods. However, the time factor is always considered explicitly in reality when making bidding decisions. A decision maker will always wonder whether there will be better projects in the future and whether his/her company should give up bidding for the present projects. The timeline of the thesis model is six months. In each month, there are several projects for bid and the projects in different months will compete for the resources in those months when the projects' production schedules overlap (since production time of a project can be more than one month in the model). The projects competing for resources make the decision maker consider trade-offs between the projects in different months.

3.3 Behavior of the Model

The model is mixed-integer and nonlinear. The bid/no-bid decisions are integer variables; the pricing decisions are continuous variables. The functions of the model are listed in Table 3-2. The figures representing the functions in Table 3-2 are produced from a simple case in which there are only two projects for bid in one month, both projects are chosen to bid, and the timeline of the bidding decision is just one month.

Table 3-2 Functions of the Model

Function		Form	Figure
Profit	$\sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}(p_{ij}-c_{ij})w_{ij}(p_{ij})$	$\sum (p_{ij}-c_{ij})w_{ij}(p_{ij})$	See Figure 3-6
Production Capacity	$\sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}\frac{u_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k)$	$\sum\sum \alpha_{ij}w_{ij}(p_{ij})$	See Figure 3-7
Storage Space	$\sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}\frac{s_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k)$		See Figure 3-7
Labor	$\sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}\frac{l_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k)$		See Figure 3-7
Cash Outflow	$\sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}\frac{c_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k-ts_{ij})$		See Figure 3-8
Cash Inflow	$\sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}\frac{p_{ij}}{t_{ij}}w_{ij}(p_{ij})\mathbf{1}_{[i,i+t_{ij}-1]}(k-tc_{ij})$	$\sum\sum p_{ij}w_{ij}(p_{ij})$	See Figure 3-9
Expected Sales	$\sum_{j=1}^{n_i} x_{ij}p_{ij}w_{ij}(p_{ij})$		See Figure 3-10
ROI	$\frac{\sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}(p_{ij}-c_{ij})w_{ij}(p_{ij})}{\sum_{i=1}^{T}\sum_{j=1}^{n_i} x_{ij}c_{ij}w_{ij}(p_{ij})}$	$\frac{\sum\sum (p_{ij}-c_{ij})w_{ij}(p_{ij})}{\sum\sum c_{ij}w_{ij}(p_{ij})}$	See Figure 3-11

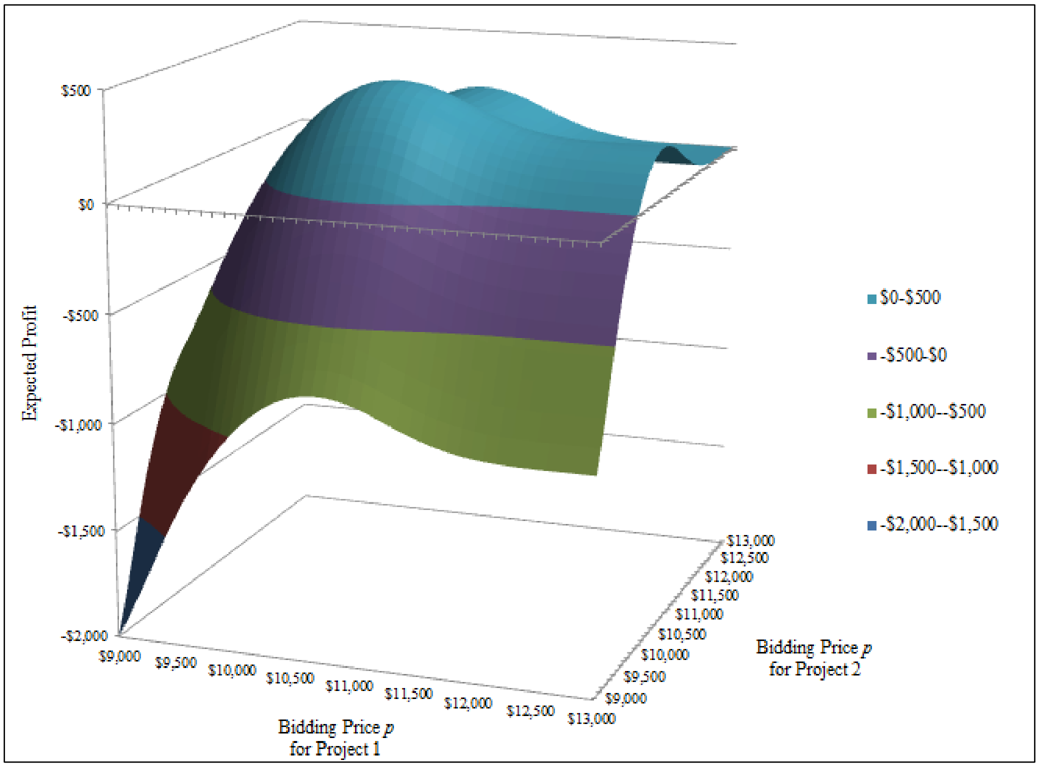


Figure 3-6 Expected Profit

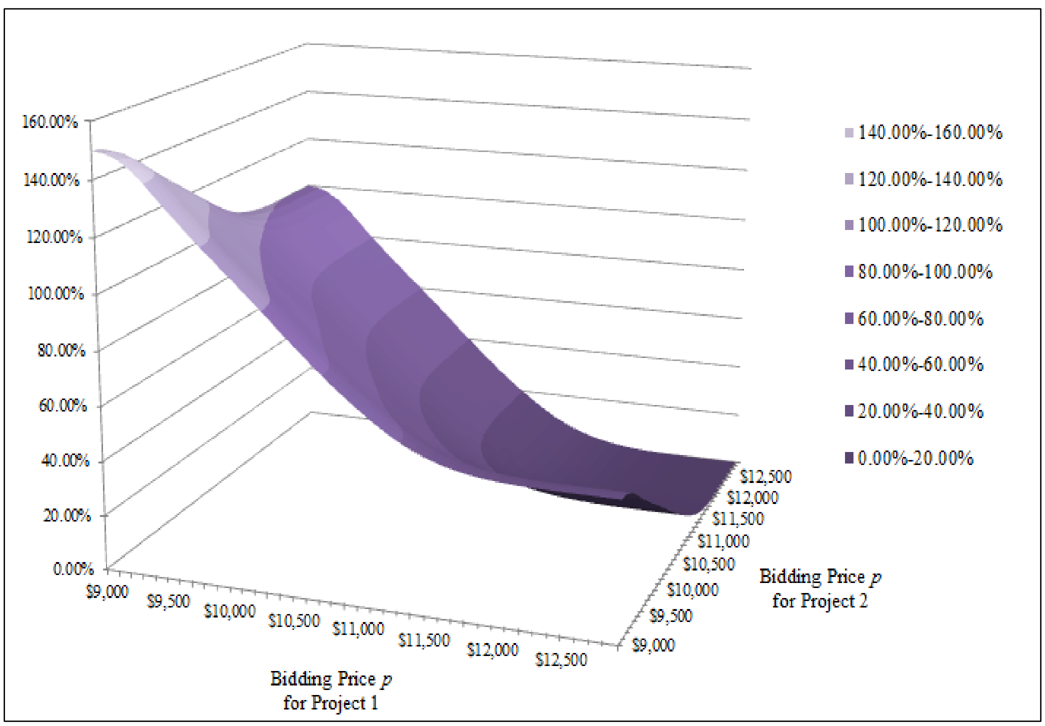


Figure 3-7 Expected Resource Utilization

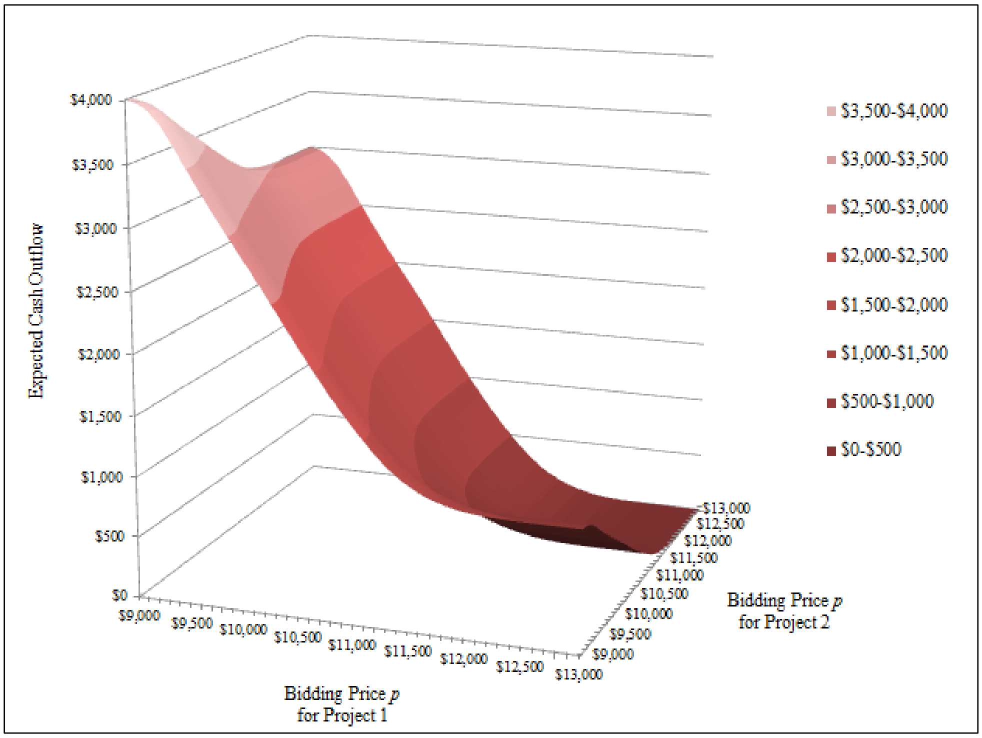


Figure 3-8 Expected Cash Outflow

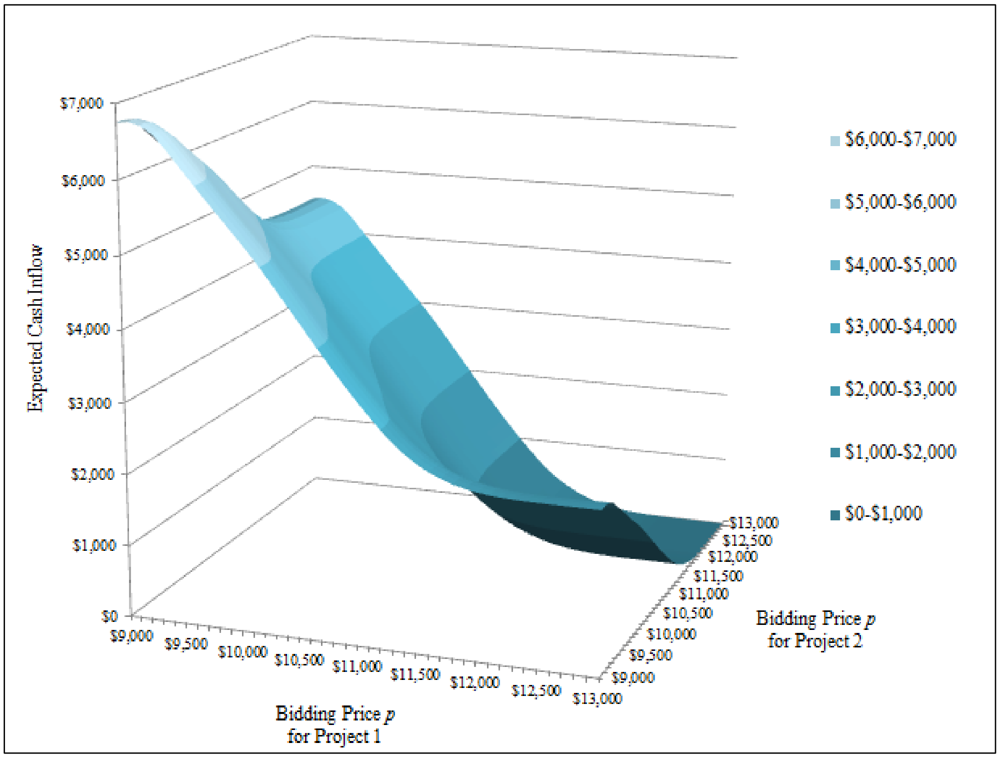


Figure 3-9 Expected Cash Inflow

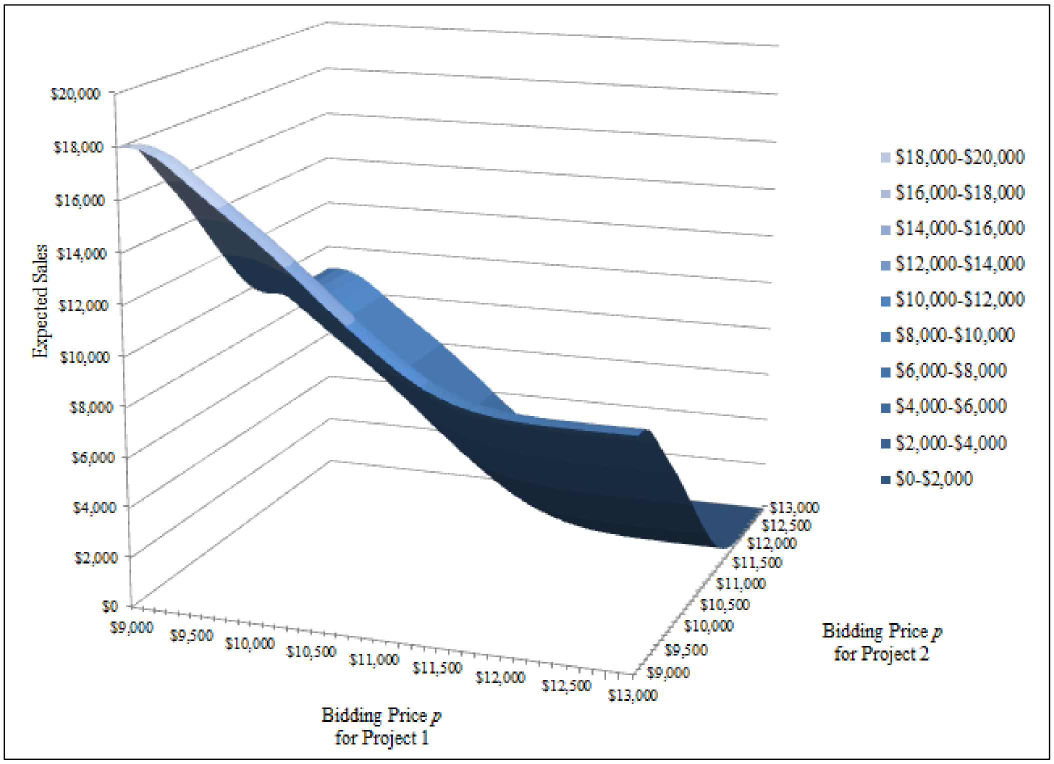


Figure 3-10 **Expected Sales**

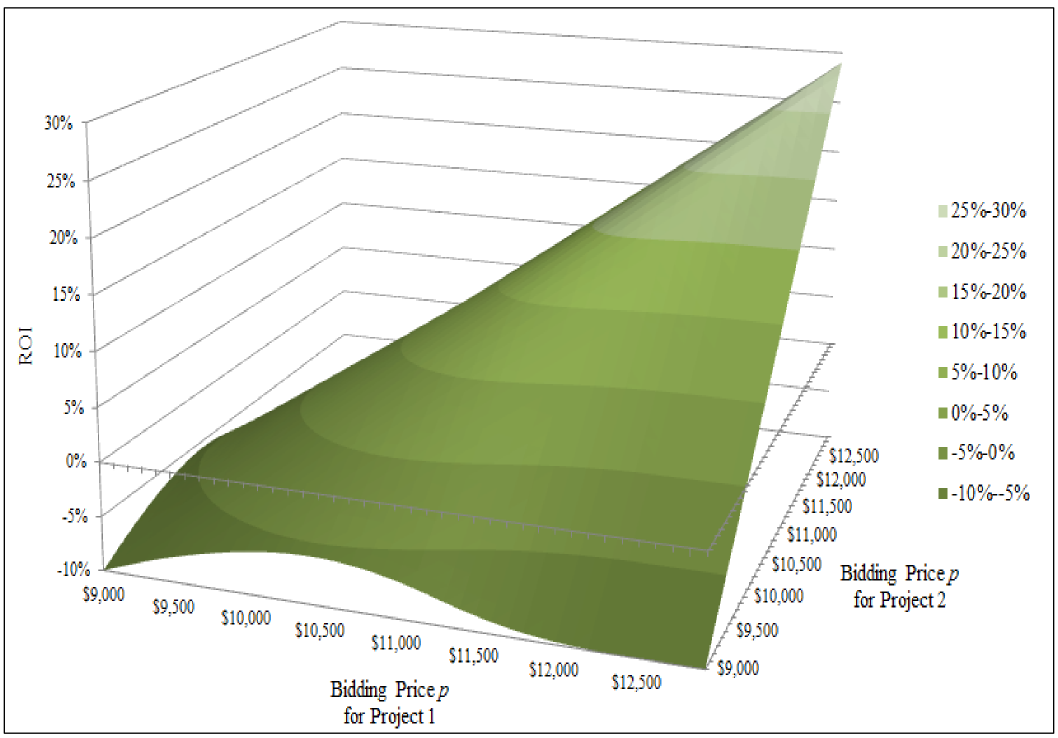


Figure 3-11 ROI

Chapter 4

Numerical Example

Bidding Decision Model

$$max \sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij}(p_{ij} - c_{ij}) w_{ij}(p_{ij})$$

$$s.t. \qquad \sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} \frac{u_{ij}}{t_{ij}} w_{ij}(p_{ij}) \mathbf{1}_{[i,i+t_{ij}-1]}(k) \le u_k \qquad k = 1, 2, 3, \dots T$$

$$\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} \frac{s_{ij}}{t_{ij}} w_{ij}(p_{ij}) \mathbf{1}_{[i,i+t_{ij}-1]}(k) \le s_k \qquad k = 1, 2, 3, \dots T$$

$$\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} \frac{l_{ij}}{t_{ij}} w_{ij}(p_{ij}) \mathbf{1}_{[i,i+t_{ij}-1]}(k) \le l_k \qquad k = 1, 2, 3, \dots T$$

$$\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} \frac{c_{ij}}{t_{ij}} w_{ij}(p_{ij}) \mathbf{1}_{[i,i+t_{ij}-1]}(k - ts_{ij}) \le ubs_k \qquad k = 1, 2, 3, \dots T$$

$$lbc_i \le \sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} \frac{p_{ij}}{t_{ij}} w_{ij}(p_{ij}) \mathbf{1}_{[i,i+t_{ij}-1]}(k - tc_{ij}) \qquad k = 1, 2, 3, \dots T$$

$$ss_i \le \sum_{j=1}^{n_i} x_{ij} p_{ij} w_{ij}(p_{ij}) \qquad i = 1, 2, 3, \dots T$$

$$roi \le \frac{\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij}(p_{ij} - c_{ij}) w_{ij}(p_{ij})}{\sum_{i=1}^{T} \sum_{j=1}^{n_i} x_{ij} c_{ij} w_{ij}(p_{ij})}$$

4.1 Description of the Example

An example is built to explain a practical implementation of the model. Consider that a decision maker is determining which projects to bid and how much to bid. The timeline of the bidding decision is six months. For each month, there are six projects for bid. For each project, there are six competitors. Tables 4-1 through 4-5 are the parameters and constraints.

Table 4-1 Production Resources Needed

Month i	**Project** j	**Production Cost** c_{ij}	**Production Capacity** u_{ij}	**Storage Space** s_{ij}	**Labor** l_{ij}
1	1	$20,000	3%	3%	3%
1	2	$40,000	6%	6%	6%
1	3	$60,000	9%	9%	9%
1	4	$80,000	11%	11%	11%
1	5	$100,000	14%	14%	14%
1	6	$120,000	17%	17%	17%
2	1	$20,000	3%	3%	3%
2	2	$40,000	6%	6%	6%
2	3	$60,000	9%	9%	9%
2	4	$80,000	11%	11%	11%
2	5	$100,000	14%	14%	14%
2	6	$120,000	17%	17%	17%
3	1	$20,000	3%	3%	3%
3	2	$40,000	6%	6%	6%
3	3	$60,000	9%	9%	9%
3	4	$80,000	11%	11%	11%
3	5	$100,000	14%	14%	14%
3	6	$120,000	17%	17%	17%
4	1	$20,000	3%	3%	3%
4	2	$40,000	6%	6%	6%
4	3	$60,000	9%	9%	9%
4	4	$80,000	11%	11%	11%
4	5	$100,000	14%	14%	14%
4	6	$120,000	17%	17%	17%
5	1	$20,000	3%	3%	3%
5	2	$40,000	6%	6%	6%
5	3	$60,000	9%	9%	9%
5	4	$80,000	11%	11%	11%
5	5	$100,000	14%	14%	14%
5	6	$120,000	17%	17%	17%
6	1	$20,000	3%	3%	3%
6	2	$40,000	6%	6%	6%
6	3	$60,000	9%	9%	9%
6	4	$80,000	11%	11%	11%
6	5	$100,000	14%	14%	14%
6	6	$120,000	17%	17%	17%

Table 4-2 Competitors' Production Costs

Month i	Project j	$ceil_{ij}$	c_{ij1}	c_{ij2}	c_{ij3}	c_{ij4}	c_{ij5}	c_{ij6}
1	1	$26,000	$19,000	$19,000	$20,000	$20,000	$21,000	$21,000
1	2	$52,000	$38,000	$38,000	$40,000	$40,000	$42,000	$42,000
1	3	$78,000	$57,000	$57,000	$60,000	$60,000	$63,000	$63,000
1	4	$104,000	$76,000	$76,000	$80,000	$80,000	$84,000	$84,000
1	5	$130,000	$95,000	$95,000	$100,000	$100,000	$105,000	$105,000
1	6	$156,000	$114,000	$114,000	$120,000	$120,000	$126,000	$126,000
2	1	$26,000	$19,000	$19,000	$20,000	$20,000	$21,000	$21,000
2	2	$52,000	$38,000	$38,000	$40,000	$40,000	$42,000	$42,000
2	3	$78,000	$57,000	$57,000	$60,000	$60,000	$63,000	$63,000
2	4	$104,000	$76,000	$76,000	$80,000	$80,000	$84,000	$84,000
2	5	$130,000	$95,000	$95,000	$100,000	$100,000	$105,000	$105,000
2	6	$156,000	$114,000	$114,000	$120,000	$120,000	$126,000	$126,000
3	1	$26,000	$19,000	$19,000	$20,000	$20,000	$21,000	$21,000
3	2	$52,000	$38,000	$38,000	$40,000	$40,000	$42,000	$42,000
3	3	$78,000	$57,000	$57,000	$60,000	$60,000	$63,000	$63,000
3	4	$104,000	$76,000	$76,000	$80,000	$80,000	$84,000	$84,000
3	5	$130,000	$95,000	$95,000	$100,000	$100,000	$105,000	$105,000
3	6	$156,000	$114,000	$114,000	$120,000	$120,000	$126,000	$126,000
4	1	$26,000	$19,000	$19,000	$20,000	$20,000	$21,000	$21,000
4	2	$52,000	$38,000	$38,000	$40,000	$40,000	$42,000	$42,000
4	3	$78,000	$57,000	$57,000	$60,000	$60,000	$63,000	$63,000
4	4	$104,000	$76,000	$76,000	$80,000	$80,000	$84,000	$84,000
4	5	$130,000	$95,000	$95,000	$100,000	$100,000	$105,000	$105,000
4	6	$156,000	$114,000	$114,000	$120,000	$120,000	$126,000	$126,000
5	1	$26,000	$19,000	$19,000	$20,000	$20,000	$21,000	$21,000
5	2	$52,000	$38,000	$38,000	$40,000	$40,000	$42,000	$42,000
5	3	$78,000	$57,000	$57,000	$60,000	$60,000	$63,000	$63,000
5	4	$104,000	$76,000	$76,000	$80,000	$80,000	$84,000	$84,000
5	5	$130,000	$95,000	$95,000	$100,000	$100,000	$105,000	$105,000
5	6	$156,000	$114,000	$114,000	$120,000	$120,000	$126,000	$126,000
6	1	$26,000	$19,000	$19,000	$20,000	$20,000	$21,000	$21,000
6	2	$52,000	$38,000	$38,000	$40,000	$40,000	$42,000	$42,000
6	3	$78,000	$57,000	$57,000	$60,000	$60,000	$63,000	$63,000
6	4	$104,000	$76,000	$76,000	$80,000	$80,000	$84,000	$84,000
6	5	$130,000	$95,000	$95,000	$100,000	$100,000	$105,000	$105,000
6	6	$156,000	$114,000	$114,000	$120,000	$120,000	$126,000	$126,000

Table 4-3 Competitors' Desire Rates

Month i	**Project** j	d_{ij1}	d_{ij2}	d_{ij3}	d_{ij4}	d_{ij5}	d_{ij6}
1	1	30%	60%	30%	60%	30%	60%
1	2	30%	60%	30%	60%	30%	60%
1	3	30%	60%	30%	60%	30%	60%
1	4	30%	60%	30%	60%	30%	60%
1	5	30%	60%	30%	60%	30%	60%
1	6	30%	60%	30%	60%	30%	60%
2	1	30%	60%	30%	60%	30%	60%
2	2	30%	60%	30%	60%	30%	60%
2	3	30%	60%	30%	60%	30%	60%
2	4	30%	60%	30%	60%	30%	60%
2	5	30%	60%	30%	60%	30%	60%
2	6	30%	60%	30%	60%	30%	60%
3	1	30%	60%	30%	60%	30%	60%
3	2	30%	60%	30%	60%	30%	60%
3	3	30%	60%	30%	60%	30%	60%
3	4	30%	60%	30%	60%	30%	60%
3	5	30%	60%	30%	60%	30%	60%
3	6	30%	60%	30%	60%	30%	60%
4	1	30%	60%	30%	60%	30%	60%
4	2	30%	60%	30%	60%	30%	60%
4	3	30%	60%	30%	60%	30%	60%
4	4	30%	60%	30%	60%	30%	60%
4	5	30%	60%	30%	60%	30%	60%
4	6	30%	60%	30%	60%	30%	60%
5	1	30%	60%	30%	60%	30%	60%
5	2	30%	60%	30%	60%	30%	60%
5	3	30%	60%	30%	60%	30%	60%
5	4	30%	60%	30%	60%	30%	60%
5	5	30%	60%	30%	60%	30%	60%
5	6	30%	60%	30%	60%	30%	60%
6	1	30%	60%	30%	60%	30%	60%
6	2	30%	60%	30%	60%	30%	60%
6	3	30%	60%	30%	60%	30%	60%
6	4	30%	60%	30%	60%	30%	60%
6	5	30%	60%	30%	60%	30%	60%
6	6	30%	60%	30%	60%	30%	60%

Table 4-4 Constraints of Production Resources

Month k	Production Capacity u_k	Storage Space s_k	Labor l_k
1	10%	10%	10%
2	12%	12%	12%
3	14%	14%	14%
4	16%	16%	16%
5	18%	18%	18%
6	20%	20%	20%
7	22%	22%	22%
8	24%	24%	24%
9	26%	26%	26%
10	28%	28%	28%
11	29%	29%	29%
12	30%	30%	30%

Table 4-5 Constraints of Cash Outflow, Cash Inflow, Sales, and ROI

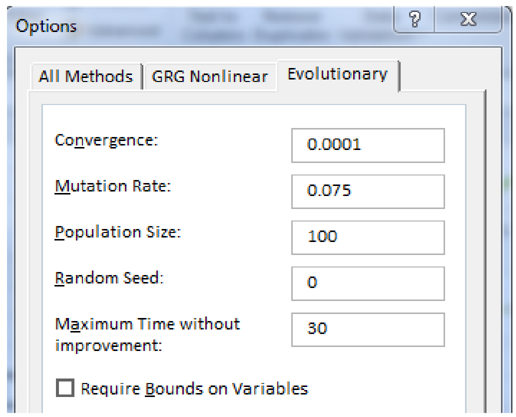
Month k	Cash Outflow ubc_k	Cash Inflow lbc_k	Sales ss_k	ROI roi
1	$20,000	$0	$100,000	5.00% (Overall)
2	$40,000	$10,000	$100,000	
3	$60,000	$20,000	$100,000	
4	$80,000	$30,000	$100,000	
5	$100,000	$40,000	$100,000	
6	$120,000	$50,000	$100,000	
7	$140,000	$60,000	$0	
8	$160,000	$70,000	$0	
9	$180,000	$80,000	$0	
10	$200,000	$90,000	$0	
11	$220,000	$100,000	$0	
12	$240,000	$110,000	$0	

4.2 Solution of the Example

The evolutionary solver is used to solve the example given the parameters and constraints.

Solving process:

1. **Set the option of the evolutionary solver as below.**



2. **Only include the production resource constraints (production capacity, storage space, and labor) in the solver.** If the solver also includes the constraints of the cash outflow, cash inflow, sales, and ROI, it will be difficult for the solver to find feasible solutions within just a few runs or there may even be no feasible solutions. The feasible region when considering all the constraints is non-convex, while the feasible region when considering only the constraints of the production resources is convex.

3. **Set the initial solution as $(x_{ij}, p_{ij}) = (0, 1.1 * c_{ij})$ for all (i, j).** The initial solution is feasible if only the production resource constraints are included in the solver and is infeasible if other constraints are included as well.

4. **Run the solver until the constraints of the cash outflow, cash inflow, sales, and ROI are acceptable for the decision maker.** Though the solver cannot provide optimal solutions, the solutions appearing in the solving process can still be evaluated against the optimal expected profit when no constraints are considered at all (i.e., $82,500).

Follow the solving process and run the evolutionary solver 68 times. The result is described as below.

1. Solution of the Example after 68 Runs

Table 4-6 Solution of Example

Month	Project	Bid/No-Bid	Price
1	1	0	$1,143
1	2	1	$42,714
1	3	1	$63,774
1	4	1	$84,864
1	5	0	$93,183
1	6	0	$155,822
2	1	1	$21,405
2	2	1	$42,724
2	3	1	$63,816
2	4	1	$85,740
2	5	0	$46,012
2	6	0	$25,748
3	1	1	$21,215
3	2	1	$42,528
3	3	1	$63,408
3	4	0	$64,607
3	5	1	$105,951
3	6	0	$1,213
4	1	1	$21,120
4	2	1	$42,462
4	3	0	$47,607
4	4	0	$16,833
4	5	1	$105,828
4	6	0	$94
5	1	1	$21,161
5	2	1	$43,943
5	3	1	$63,646
5	4	0	$75,469
5	5	1	$105,909
5	6	1	$127,200
6	1	0	$15,515
6	2	1	$42,228
6	3	1	$63,681
6	4	0	$36,423
6	5	1	$105,874
6	6	0	$92,591

2. Constraints of Production Capacity, Storage Space, and Labor

Table 4-7 Production Resource Needed for Solution

Month *k*	Production Capacity		Storage Space		Labor	
	Need	Constraint (Upper Bound)	Need	Constraint (Upper Bound)	Need	Constraint (Upper Bound)
1	9.00%	10%	9.00%	10%	9.00%	10%
2	12.00%	12%	12.00%	12%	12.00%	12%
3	12.89%	14%	12.89%	14%	12.89%	14%
4	15.69%	16%	15.69%	16%	15.69%	16%
5	17.99%	18%	17.99%	18%	17.99%	18%
6	16.39%	20%	16.39%	20%	16.39%	20%
7	11.82%	22%	11.82%	22%	11.82%	22%
8	1.52%	24%	1.52%	24%	1.52%	24%
9	0.00%	26%	0.00%	26%	0.00%	26%
10	0.00%	28%	0.00%	28%	0.00%	28%
11	0.00%	29%	0.00%	29%	0.00%	29%
12	0.00%	30%	0.00%	30%	0.00%	30%

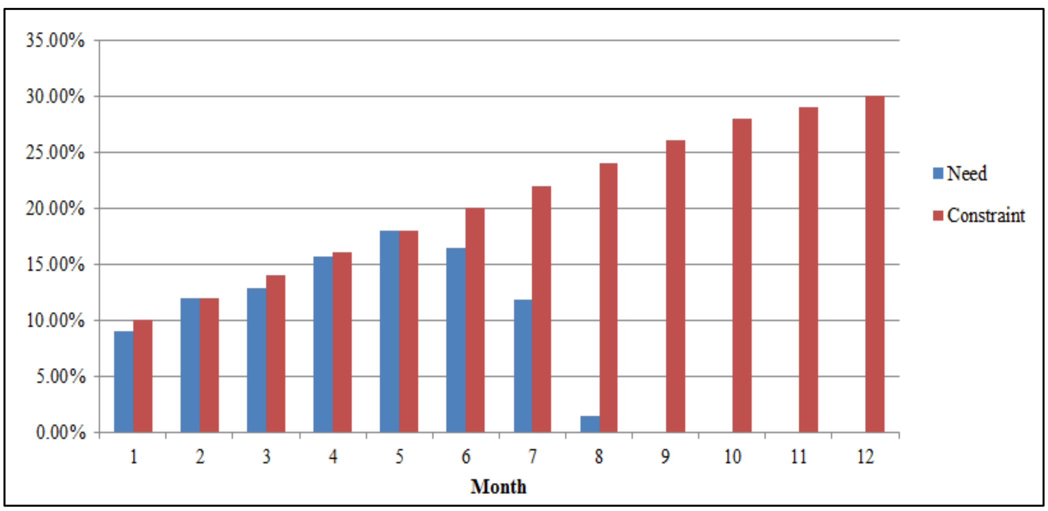


Figure 4-1 Production Capacity Needed for Solution

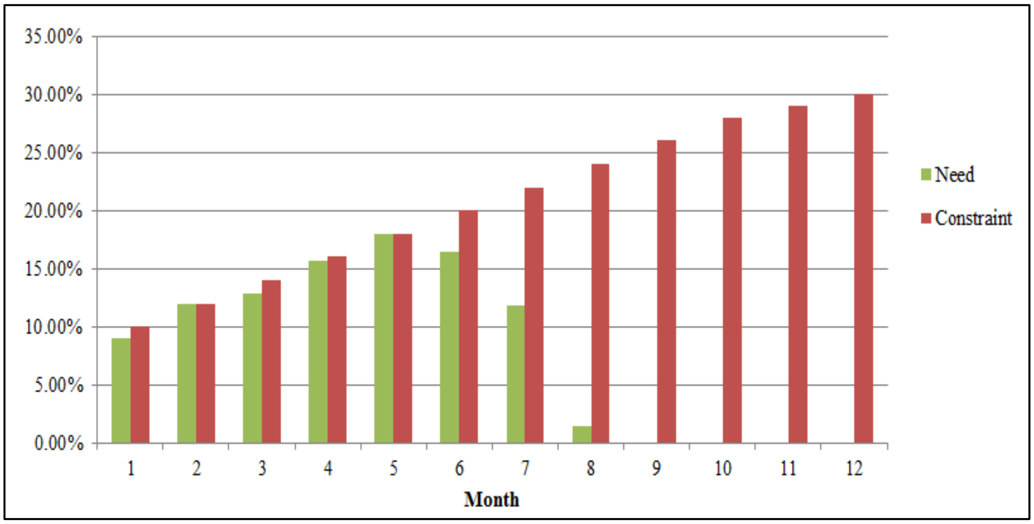


Figure 4-2 Storage Space Needed for Solution

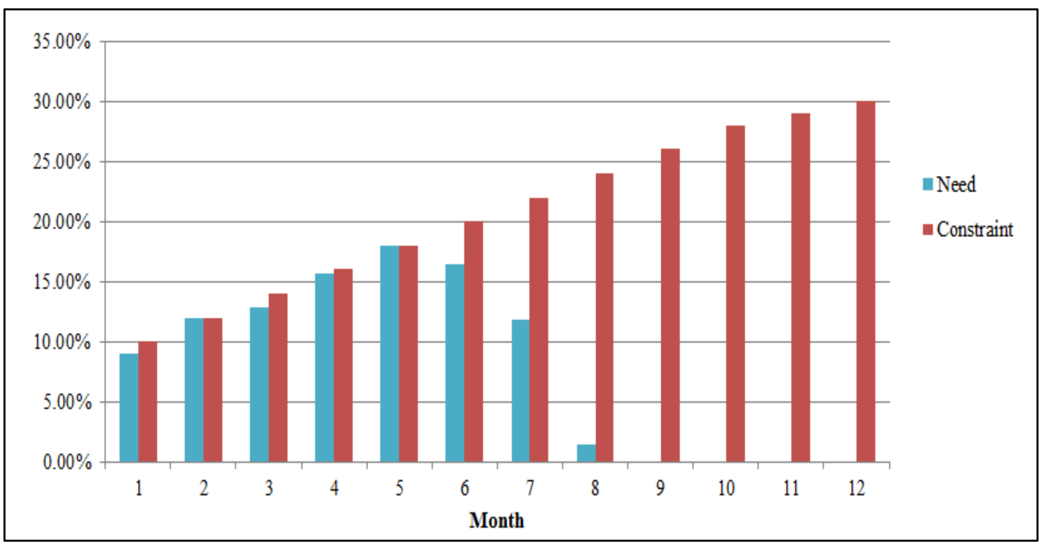


Figure 4-3 Labor Needed for Solution

Figures 4-1, 4-2, and 4-3 show that a decision maker can easily determine how the production resources are needed or utilized given the solution. Since the projects available for bid are only spread in the first six months, the resources needed after the sixth month are decreasing.

3. Constraints of Cash Outflow, Cash Inflow, Sales, and ROI.

Table 4-8 implies that the solution after 68 runs is quasi-feasible, since most of the constraints of cash outflow, cash inflow, and sales are satisfied after 68 runs.

Table 4-8 Cash Outflow, Cash Inflow, Sales, and ROI Generated by Solution

Month *k*	Cash Outflow		Cash Inflow		Sales		ROI	
	Amount	Constraint (Upper Bound)	Amount	Constraint (Lower Bound)	Amount	Constraint (Lower Bound)	%	Constraint (Lower Bound)
1	$0	$20,000	$0	$0	$99,178	$100,000		
2	$10,400	$40,000	$10,160	$10,000	$100,515	$100,000		
3	$63,754	$60,000	$31,328	$20,000	$127,995	$100,000		
4	$85,976	$80,000	$117,913	$30,000	$94,109	$100,000		
5	$51,498	$100,000	$162,640	$40,000	$183,690	$100,000		
6	$102,937	$120,000	$109,472	$50,000	$117,454	$100,000		
7	$130,983	$140,000	$134,704	$60,000	$0	$0	6.15%	5.00%
8	$113,912	$160,000	$99,515	$70,000	$0	$0		
9	$82,129	$180,000	$45,882	$80,000	$0	$0		
10	$39,455	$200,000	$11,326	$90,000	$0	$0		
11	$0	$220,000	$0	$100,000	$0	$0		
12	$0	$240,000	$0	$110,000	$0	$0		
Sum	$681,044		$722,941		$722,941			

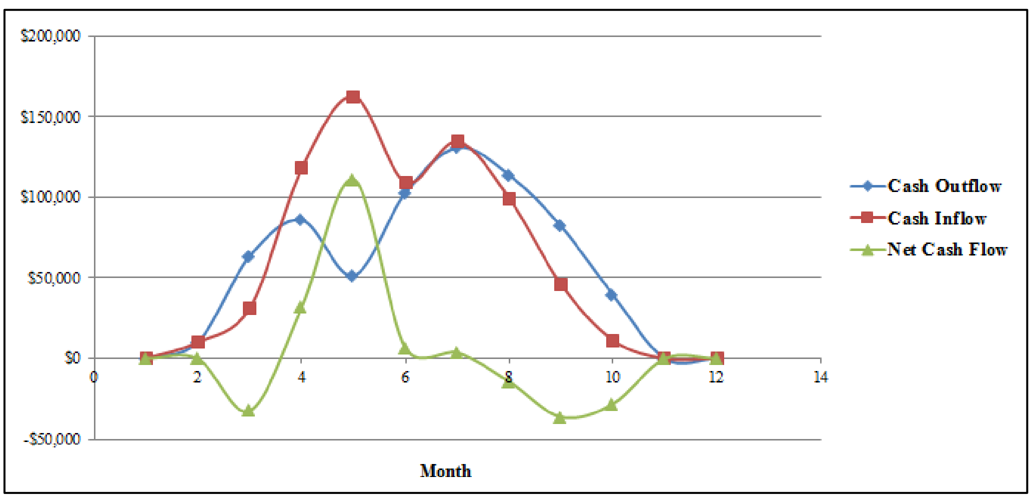


Figure 4-4 Cash Flow Generated by Solution

Figure 4-4 illustrates that a decision maker can easily observe the trend of cash flow over the 12 months and decide whether the cash flow is acceptable.

4. Objective Function (Expected Profit)

Table 4-9 Expected Profits at Different Runs

Run	Expected Profit	Run	Expected Profit
0*	$0		
1	$27,524	31	$37,945
2	$31,419	32	$39,586
3	$31,441	33	$40,881
4	$31,646	34	$40,912
5	$32,025	35	$40,912
6	$32,189	36	$40,912
7	$32,208	37	$40,933
8	$32,242	38	$40,941
9	$32,242	39	$40,965
10	$32,242	40	$40,965
11	$32,242	41	$40,965
12	$32,242	42	$40,973
13	$32,242	43	$40,973
14	$32,243	44	$40,975
15	$36,290	45	$40,975
16	$36,290	46	$40,979
17	$36,290	47	$41,646
18	$36,292	48	$41,650
19	$36,292	49	$41,662
20	$36,292	50	$41,700
21	$36,395	51	$41,808
22	$36,413	52	$41,808
23	$36,413	53	$41,856
24	$37,861	54	$41,856
25	$37,914	55	$41,857
26	$37,914	56	$41,857
27	$37,914	57	$41,857
28	$37,928	58	$41,857
29	$37,945	59	$41,857
30	$37,945	60	$41,857

*initial solution

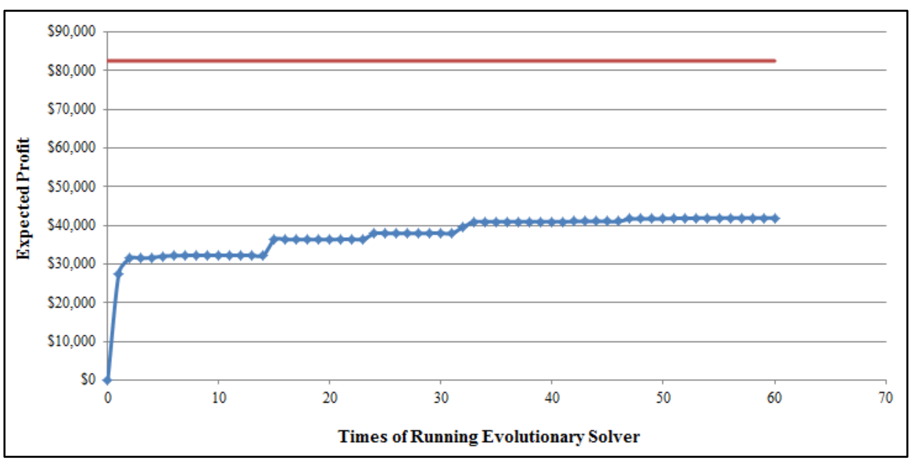


Figure 4-5 Expected Profits at Different Runs

Figure 4-5 shows that, as the number of runs increases, the expected profit improves. The red line, $82,500, is the optimal expected profit given no constraints and is used as an upper bound.

Chapter 5

Conclusions

In this thesis, which was inspired by a small Taiwanese manufacturer producing coal pipelines for power stations, a bidding decision model considering the bidding patterns of competitors for SMEs has been developed. The model reflects that SMEs need an easy-to-implement bidding strategy that should consider not only production management but also financial management. The model built in the thesis differs from other models in the method of developing the bidding patterns of competitors. The development of bidding patterns of competitors does not rely on past bidding data of competitors but on the understanding of those competitors. The understanding is represented by two terms, *production costs of competitors* and *desire rates*. *Triangular distribution* is used to model the bidding patterns of competitors. The uncertainties of bidding prices submitted by competitors are included not only in the objective function of the model (expected profit) but also in all constraints. Production and cash flow management are also reflected in the constraints. The model also considers trade-offs between projects in different time periods.

Since the constraints of the model include the probability functions of winning projects, all constraints are nonlinear. Further, triangular distribution also makes the probability functions not smooth. Therefore, it is difficult to solve the model when simultaneously considering all the constraints; therefore, the solver only considers the production resource constraints and leaves the other constraints for the decision maker to monitor. The solver will be run iteratively to improve the objective (expected profit), and the decision maker can observe the patterns of cash flows and performances of sales and ROI to decide when to stop the solving process and accept the updated solution. The record of the solving process can tell the decision maker how the objective and constraint functions change as the solution changes and he/she can determine whether a further run or restart is needed.

For future research on bidding strategy, how to estimate the probability of winning a project is still a core issue. There are many kinds of uncertainties contributing to the uncertainty of winning a project that deserve deeper and broader research. To develop a successful bidding strategy for an industry or company, researchers can further examine the business mechanism of the industry or company. A bidding strategy that is inspired by business facts not only appears realistic but is also easy to understand and implement. However, a general bidding strategy is still desired because it is not only more valued in the academic community but also provides a thinking framework for practitioners when dealing with bidding problems.

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